T-Mobile QoE Lab – How We Are Making Your Mobile Browsing Faster and Research Problems That We Are Facing

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ABSTRACT
T-Mobile is looking at all possible ways to optimize quality of user experience (QoE) for our customers in balance with our network resources and device energy consumptions.

In the mobile smart phone world, the misperception that people often held about use experience is the faster the network speed is, the faster the phone CPU speed is, the better the quality of experience (QoE) is. On the contrary, we intend to use three practical examples to unveil the mystery behind the mobile network black box and illustrate it is the end-to-tend (E2E) latency impacts the QoE of one of the most commonly used data services – mobile browsing.

A lengthy E2E latency due to rarely-understood and hard-to-uncovered phone or network issues may render a very poor browsing page loading speed even if you have a super hero dual core smart phone with the fastest 4G network speed. In order to understand the E2E latency better in the transient wireless channel conditions and optimize data QoE in a much faster way, we advocate the use of the Cross-device/network evaluation methodology.

Finally, we presented a few research questions that we are facing and solicit research community's input.

Categories and Subject Descriptors
C 2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *Wireless communication.* C 4 [**PERFORMANCE OF SYSTEMS**]: Measurement techniques, Performance attributes

General Terms
Performance, Experimentation, Measurement

Keywords
Quality of User Experience (QoE), mobile browsing, smart phone, end-to-end latency, 4G wireless network, transient state

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1. THE IMPACT OF E2E LATENCY ON MOBILE QOE
Looking into most commonly used service - mobile browsing, this section uses three examples to illustrate some rarely understood conditionings by mobile device and network, and therefore demonstrates the importance of E2E latency on mobile QoE.

Through the examples, we also advocate looking into anomalies in long tails, and the methodology of driving optimizations with thread of identifying issues of "device QoE" to understanding "traffic pattern" to root-cause analysis of the "mobile conditioning", because practice proves with this methodology we are able to uncover a network design issue which has existed for eleven years since beginning of the product but unnoticed till now.

1.1 Mystery 1: Long DNS Lookup Time

1.1.1 Device QoE
The first network round trip time (RTT) in mobile browsing is DNS lookup time if the IP address for the site is not yet resolved and cached in the mobile device.

However, we found discrepancy between network viewed average DNS lookup time (around 200ms) and individual device test results:

- Network side: aggregated average DNS lookup = 222 ms;
- Device side: 'Curious George' engineers looked into distribution of DNS lookup time from device testing and found outliers (10s+), such as shown in Figure 1.

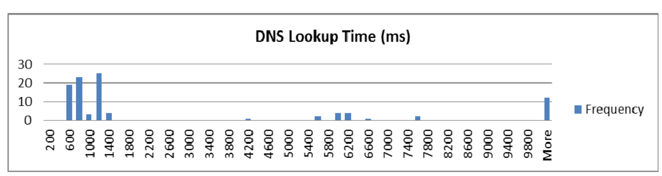

Figure 1. DNS lookup time distribution of device testing.

1.1.2 Traffic Pattern
When we analyze the traffic pattern (Figure 2) from packet trace, we can see the DNS response is lost therefore device will retransmit DNS Query after a timeout (in the case, it is 5s in

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Android system). Here UE stands for User Equipment, and RAN stands for Radio Access Network. UE and device or mobile device will be used interchangeable in this publication.

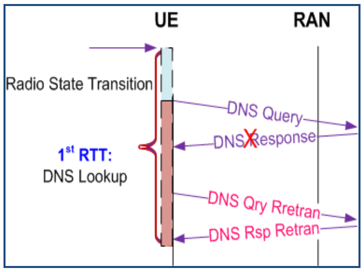

Figure 2. Traffic pattern of Mystery 1.

1.1.3 Mobile Conditioning

Cross layer analysis in Figure 3 shows the root cause of Data Stall #1 associated with Mystery 1 is that Radio network controller corrupts downlink packets due to cipher key out-of-synch after radio state transition (Cell PCH → Cell FACH).

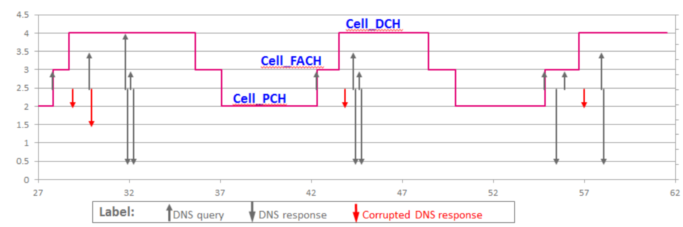

Figure 3. Cross-layer analysis of Mystery 1.

After the problem is fixed, the benefits show DNS lookup time during this erroneous scenario (DNS lookup sent during Cell_PCH state) is reduced on average from 3.7s to 0.7s as shown in Figure 4.

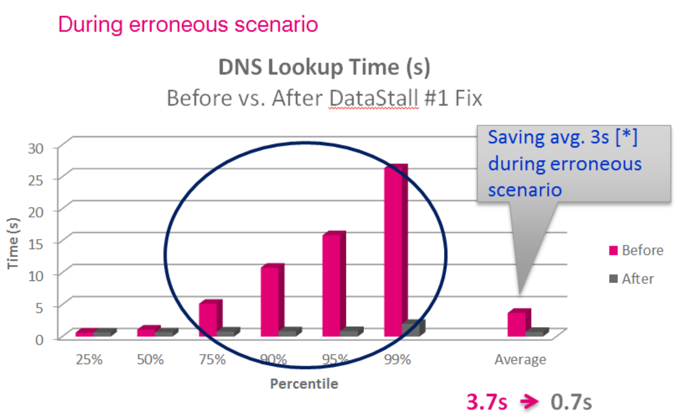

Figure 4. Before and after comparison of Data stall #1 fix.

1.2 Mystery 2: Long TCP Connect Time

1.2.1 Device QoE

When we look into the next RTT of browsing, the TCP connection time based on TCP three-way handshaking from SYN to SYN/ACK also is still not ideal with 95% percentile close to 4s.

1.2.2 Traffic Pattern

Analysis of packet trace shows traffic pattern as in Figure 5. TCP SYN/ACK from network side in response to the TCP SYN was delayed extensively in the RAN and causes the device to retransmit the TCP SYN again.

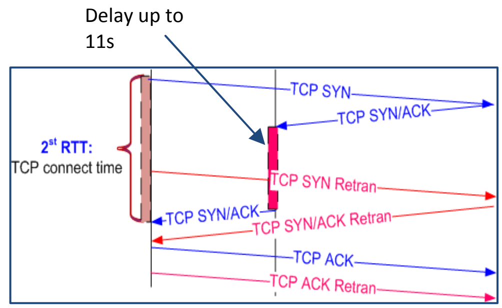

Figure 5. Traffic pattern of Mystery 2.

1.2.3 Mobile Conditioning

Cross layer analysis shows the root cause of Data Stall #2 associated with Mystery 2 is that Radio network controller scheduler unnecessarily buffer DL packets up to 11s due to a bug in credit based scheduling algorithm between NodeB and RNC → causes UL RLC retransmissions and RESETs.

After the problem is fixed, the benefits show TCP connect time is reduced on average from 0.95s to 0.8s.

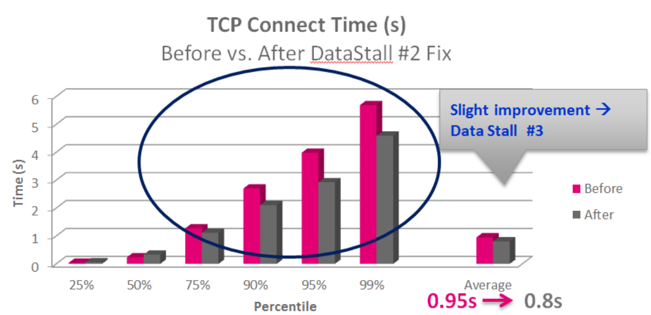

Figure 6. Before and after comparison of Data stall #2 fix.

1.3 Mystery 3: TCP Connect Time Still Long

1.3.1 Device QoE

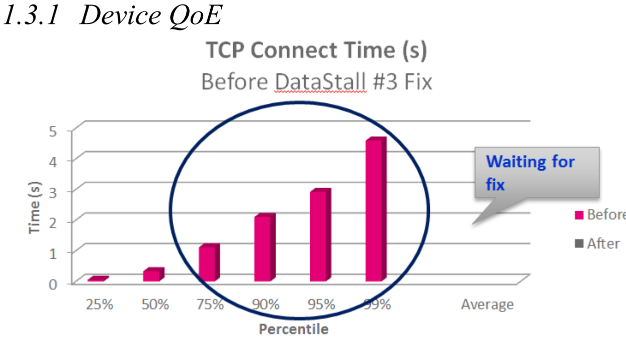

Figure 7. Distribution of TCP connect time in Mystery 3.

The TCP RTT after data stall 2 is fixed still shows 95% percentile close to 3s as shown in Figure 7 based on device testing, though improved over before.

1.3.2 Traffic Pattern

Analysis of packet trace shows traffic pattern as in Figure 8. TCP SYN from the device in the uplink is dropped by the RAN therefore causes the device to retransmit the TCP SYN again.

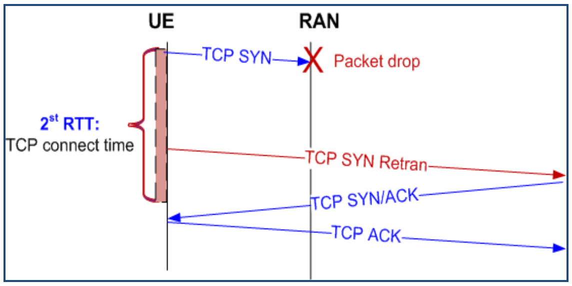

Figure 8. Traffic pattern of Mystery 3.

1.3.3 Mobile Conditioning

Cross layer analysis shows the root cause of Data Stall #3 is that Radio network controller UL scheduler drops UL packets during channel switching from DCH to FACH, same problem happens during other radio state or transport channel switchings such as HS←→R99, DCH←→FACH.

2. QOE LAB

The three case studies presented above were done in QoE lab of T-Mobile. Unique approach is taken in the lab:

- Measure end user experiences from the device perspective
- Seek success by improving not only averages but also the spread and long tail
- Leverage key industry and academic partners for joint R&D and Real User Measurement (RUM)
- Analyze cross functionally to achieve cross layer intelligence and automation

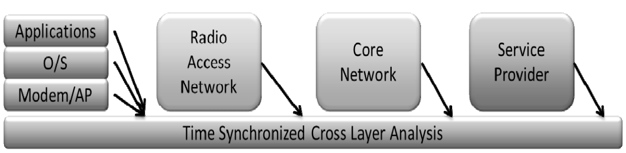

Figure 9. Cross-Layer/Network Approach Taken in QoE Lab.

We are looking for top minds from research community to help answer the questions that we are facing.

2.1 Transient State Performance and Resilience

Research Problem:

- Automatically characterize and instrument transient state mobile application performance. Here transient state means the transition among the radio states of cellular network as shown in Figure 10 of either 3G/4G network or LTE network, including transitions in-between Cell_DCH and Cell_FACH or Cell/URA_PCH in UMTS/HSPA network, or connected mode and IDLE mode in LTE network, also includes the handover, cell-reselection or link failure recovery transient states.
- Packet loss and retransmissions observed during transient states
- Cross-layer analysis and optimizations are still not fully explored!

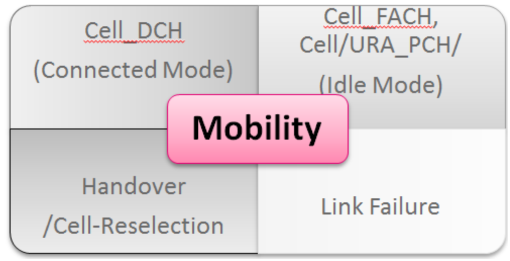

Figure 10. Radio states of cellular network.

2.2 Interactive Traffic Modeling and Scheduling

Research Problem:

- 3GPP radio scheduling designed mostly with Full Buffer Traffic model
- Higher layer scheduling (RNC, SGW) is not considered

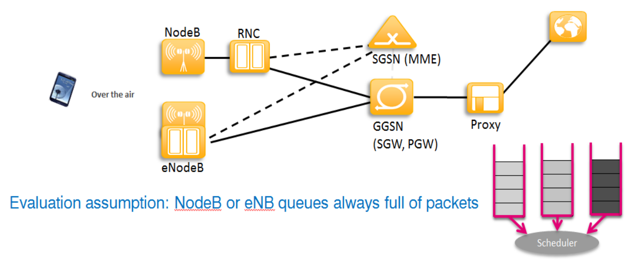

Figure 11. Cellular network architecture and current evaluation methodology of full traffic model.

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